10021543 . 121301

UNITED STATES PATENT APPLICATION

FOR

OPTICAL AMPLIFIER WITH TRANSVERSE PUMP

INVENTORS:
ANDREW C. ALDUINO
RONGCHUNG TYAN
CHRISTOPHER J. SCHOLZ

PREPARED BY:

CHARLES K. YOUNG
INTEL CORPORATION
2200 MISSION COLLEGE BLVD.
SANTA CLARA, CA 95052-8119

(408) 765-8080

Attorney's Docket No. 42390.P11010

"Express Mail" mailing label number EL821772506

Date of Deposit: December 13, 2001.

I hereby certify that I am causing this paper or fee to be deposited with the United States Postal Service "Express Mail Post Office to Addressee" service under 37 CFR 1.10 on the date indicated above and is addressed to: U.S. Patent and Trademark Office, Post Office Box 2327, Arlington, VQ, 22202

Raquel R. Torres
(Typed or printed name of person mailing paper or fee)

Raquel R. Torres
(Signature of person mailing paper or fee) Date

OPTICAL AMPLIFIER WITH TRANSVERSE PUMP

1. Field

The described invention relates to the field of optical signal amplification. In particular, the invention relates to amplifying an optical signal using transverse pumping light beams.

2. Background

A waveguide may serve as an optical amplifier by doping it with ions of a rare earth element such as Erbium. An optical signal propagating in the waveguide is amplified when a pumping light beam is introduced. For example, Erbium ions, excited to a higher energy state with a pumping light beam having a wavelength of approximately 980 nm or 1480 nm, will amplify an optical signal in a wide wavelength band around 1530-1600 nm as the Erbium ions fall down to a lower energy state. This technique is well-known in optical fiber amplification.

Figure 1 is a schematic diagram showing one prior art method of amplifying an optical signal 10 in a planar waveguide 20. The waveguide 20 is embedded in a substrate 30 and doped with Erbium ions. An optical signal 10 is directed into the waveguide 20 and propagates through the waveguide 20. A laser 50 supplies pumping light beams into the waveguide 20 in a co-propagating direction, i.e., in substantially the same direction as the optical signal propagates. The signal 10 and the pump 50 are combined to the same waveguide 20, for example, in an evanescent directional coupler. In one example, an optical signal 10 having wavelength of

approximately 1550 nm is amplified as laser 50 supplies pumping light beams of approximately 980 nm or 1480 nm wavelength.

Figure 2 is a schematic diagram showing another prior art method of amplifying an optical signal. In Figure 2, a pump laser 50 is directed from the opposite end of the waveguide 20 to pump light in a counter-propagating direction, i.e., in a direction opposite to that of the optical signal. Similar to Figure 1, the optical signal is amplified within the waveguide 20 and then exits the substrate 30.

Modern optical networks use single-mode optical fibers for transmission over long distances. This avoids signal degradation coming from chromatic dispersion, i.e. dependence of the speed of the light on its wavelength. For efficient interfacing with single mode fibers, all optical components, including fiber or waveguide amplifiers, are effectively single-mode. Due to a general principle of optics, "brightness conservation theorem", power of light in a single mode cannot be increased using just linear passive (not adding energy) optical elements. This results in a fact that the power of light with a certain wavelength from only one mode can be coupled to a single mode waveguide. For amplifiers, it translates that only one pump laser with a certain wavelength can supply pump light in each direction of propagation and each polarization.

The optical signal experiences gain in an optical amplifier provided that the intensity of the pump is higher than a certain threshold value dependent on the intensity of the optical signal and material properties of the optical amplifier. In order to achieve high enough gain, the intensity of the pump must be much higher than the threshold value. Consequently, a high power of a pump laser is typically required.

There are several disadvantages of the above methods compared to the invention described below. First, the relatively high power laser used in the described co-propagating and counter-propagating amplification is expensive. Second, high power lasers have a high power dissipation, which may cause thermal issues in their packaging. Third, the reliability of high power lasers is generally not as good as that of lower power lasers.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic diagram showing one prior art method of amplifying an optical signal in a planar waveguide.

Figure 2 is a schematic diagram showing another prior art method of amplifying an optical signal.

Figure 3 is a schematic diagram showing a top view of one embodiment of an optical amplifier.

Figure 4 is a schematic diagram showing a cross sectional view of an optical amplifier taken along line A-A' of Figure 3.

Figure 5 is a graph showing an example of increase in optical signal power based on optical pumping.

DETAILED DESCRIPTION

An apparatus and method for amplifying an optical signal in a waveguide is disclosed. In one embodiment, multiple lower power lasers are interspersed along a length of the waveguide to provide pumping light beams transverse to the direction of propagation of the optical signal.

Figure 3 is a schematic diagram showing a top view of one embodiment of an optical amplifier. An optical signal 110 enters into and propagates through waveguide 120, which is embedded in a substrate 130. There are various ways to fabricate a waveguide embedded in a substrate, such as by diffusion of various ionic species, etching, and epitaxial growth. "Embedded within a substrate" is meant to include these various ways, including silicon-on-insulator. In some cases, the waveguide may actually be deposited on top of a substrate and covered with a cladding material different from the substrate, but is also meant to be covered by the term "embedded within a substrate".

In one embodiment, waveguide 120 is a single-mode waveguide. A plurality of light sources 150, such as laser diodes, are coupled to the substrate 130 to direct the pumping light beams substantially transverse to the embedded waveguide 120.

In one embodiment, the light sources 150 are spaced evenly apart along the length of the embedded waveguide 120. However, other embodiments may include different spacings between light sources 150. In one embodiment, the light sources 150 comprise vertical cavity surface emitting lasers (VCSELs). The VCSELS may be fabricated from a common semiconductor substrate 155 and may be bonded to a

surface of the device substrate 130. This allows lithographically-defined spacing between the VCSELs.

In one embodiment, the VCSELs use relatively low power. For example, a VCSEL may emit, but is not limited to, less than 20 mW of power. Comparable high power lasers used in co-propagating and counter-propagating architectures use higher power lasers, such as, but not limited to, 100 mW.

Figure 4 is a schematic diagram showing a cross sectional view of an optical amplifier taken along line A-A' of Figure 3. In one embodiment, after the pumping light beam 160 from the light source 150 passes through the waveguide 120, the pumping light beam is reflected off a lower surface 180 and sent back to the waveguide 120, as shown by arrows 170. In one embodiment, the reflection at lower surface 180 is due to a change in refractive index, which may be achieved by the lower surface 180 adjoining either a different material, or the same material but having different properties, as is well-known. In one embodiment, the lower surface 180 is adjoining to air or to a heatsink.

In one embodiment, the spacing between the light source 150 and the embedded waveguide 120 is relatively small, e.g., 5 microns. In another embodiment, a lens or collimator may be coupled between the light sources and the substrate.

Figure 5 is an example graph illustrating an increase in optical signal power based on the optical pumping. In one embodiment, the pumping light beams have a power P_{PUMP} that is applied to the optical signal 200. The pump power P_{PUMP} 202 is greatest directly under a light source 210. As the optical signal 200 propagates through the waveguide, it is successively pumped by multiple light sources 210.

In one embodiment, multiple waveguides may be embedded in the same substrate. Each waveguide may have a set of transverse pumps for amplifying an optical signal within the waveguide. In one embodiment, the transverse pumps are VCSELs. A matrix of VCSELs fabricated on a common substrate may be used to amplify optical signals in multiple waveguides.

Thus, an apparatus and method for amplifying an optical signal is disclosed. However, the specific arrangements and methods described herein are merely illustrative. For example, there are various ways to fabricate a waveguide embedded in a substrate, such as by diffusion of various ionic species, etching, and epitaxial growth. One skilled in the art could use any of various methods to fabricate such an embedded waveguide. Numerous modifications in form and detail may be made without departing from the scope of the invention as claimed below. The invention is limited only by the scope of the appended claims.